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DESIGN OF RECENT ADDITIONS TO  
KEY WEST AQUEDUCT

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## DESIGN OF RECENT ADDITIONS TO KEY WEST AQUEDUCT

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Key West, despite the fact that fresh water in quantity was never locally available, has been an inhabited island for more than a century. The records of the U. S. Census Bureau go back as far as 1860, when a population of 2832 was reported. The provision of facilities which would deliver an adequate supply of fresh water from the mainland had been an ambition of the civilian population of Key West for many years before the Key West Aqueduct was completed in 1942.

Prior to the completion of the Overseas Branch of the Florida East Coast Railroad between Miami and Key West in 1912, all fresh water for the inhabitants was secured from roof drainage directed into the cisterns of the individual householders, and those cisterns were frequently augmented and replenished by fresh water brought by boat and barge from the mainland. The provision of rail service in 1912 made it possible to bring in fresh water from the mainland by tank car, and the "consist" of daily freight trains included several tank carloads of fresh water, for Key West and for the settlements along the "Upper Keys" (the numerous islands traversed by the railroad).

The desires and ambitions of the people within a particular geographic area are sometimes frustrated by conditions and events beyond their control. Despite the fact that the railroad was completed into Key West in 1912, the Florida State census in 1915 reported a population loss of 2,000 in the preceding ten (10) year interval, and the Upper Keys meanwhile had gained in population by approximately 650. Census records indicate that Key West diminished in population rather steadily from 20,498 reported for 1905, to 12,317 reported in 1935. During this interval, Key West had lost the cigar industry to Tampa, and the principal economy was dependent upon fishing, and the fact that Key West was the rail and ferry terminus for the Miami to Havana tourist traffic. However, in 1935 the Overseas Branch of the Florida East Coast Railroad was severely damaged by an intense hurricane. Rail traffic had diminished to the point where the railroad management decided to abandon the branch and salvage the track rather than to rebuild. As a result of this decision, which was made at a time when Key West was in the economic depths, the economic fortunes of Key West took a turn for the better and have steadily improved.

With the abandonment of the railroad, the Florida State Legislature created the Overseas Road and Toll Bridge District for the distinct purpose of providing a modern highway from the mainland to Key West and utilizing the old railroad right-of-way and as many as possible of the railroad bridges. The construction of this modern toll highway was not fully completed when the U. S. entered World War II in 1941. Despite the fact that the economic fortunes of Key West and the Upper Keys have been steadily improving since 1935, the comparatively enormous cost of providing facilities for delivering fresh water from the mainland to Key West made such an undertaking beyond

the economic reach of the civilian inhabitants until 1941. In that year, the expansion of activities at the Key West Naval Base, resulting from the National Defense effort, required the provision of an ample and dependable supply of fresh water for Navy personnel. As a result of this circumstance, the Navy Department and the civilian authorities pooled their efforts, and the present Key West Aqueduct is the result thereof. The Navy Department retained the firm of Parsons, Brinkerhoff, Hall and McDonald to prepare the plans and specifications for water supply facilities based upon securing water from wells on the mainland and pumping this water through a pipe line approximately 130 miles in length to Key West. Construction was commenced in 1941 and the total cost of the original construction was approximately \$4,500,000.00. About \$1,500,000.00 of that cost was financed by the Key West Aqueduct Commission which was created by the Florida State Legislature in 1941 and clothed with the power and authority to represent civilian interests. The remainder was financed by the Navy Department. The original facilities which were put into operation in 1942 included three (3) 10-inch wells at Florida City, a pumping station at Florida City equipped with two (2) Diesel driven centrifugal pumps, an 18-inch O. D. steel pipe line approximately 130-miles in length, and certain terminal facilities in Key West consisting primarily of master connections and master meters.

The design criteria surrounding the original facilities is not known, but the Diesel driven pumps, when operated separately, delivered approximately 2.25 M. G. D. into the Aqueduct at Florida City at a pump discharge pressure of approximately 225 p.s.i. When operated in tandem or in series, the pumps would obviously deliver slightly more water. These facilities were initially adequate, but the demand for water steadily increased, and in 1944, J. E. Griner & Company was retained by the Navy Department for the preparation of plans and specifications covering the provision of a water treatment plant at Florida City with a capacity of 2.4 M. G. D., and the provision of a Booster Pumping Station to be located at Marathon, Florida.

The water secured from the wells at Florida City has a total hardness of approximately eleven (11) grains per gallon, and the provision of the water treatment plant resulted from a desire to reduce this total hardness to approximately five (5) grains per gallon. The increase in water demand made it necessary that the original capacity of the Aqueduct be increased, and this was to be accomplished by the provision of the Booster Pumping Station, and by the provision of additional pumping capacity at Florida City. One of the Diesel driven centrifugal pumps originally installed at Florida City with a rated capacity of 1400 G. P. M. at 520 ft. T. D. H. was removed and reinstalled in the new pumping station at Marathon. Electric power meanwhile had been made available at the Florida City Pumping Station, and the pump removed to Marathon was replaced by an electric driven centrifugal pump having rated characteristics of 2100 G. P. M. at 560 ft. T. D. H. With these additions, which were completed and put into operation in 1946, it was possible to pump about 3.0 M. G. D. into the Aqueduct at Florida City.

When civilian construction again became permissible early in 1946, a rapid growth and development started along the Upper Keys and in addition the construction of housing in Key West took on new life. Consequently, the demand for water by civilian consumers increased rapidly, and the facilities of the Aqueduct were soon overtaxed. For the past several years, the existing Aqueduct facilities have not been adequate to deliver sufficient water, and the usage of water in Key West has been controlled by lowering the pressure on the water distribution system. In cognizance of this circumstance, the

Navy Department retained the services of Reynolds, Smith and Hills in the Fall of 1951, to make a thorough engineering study and survey of the Key West Aqueduct System and to determine the extent and magnitude of additional system facilities deemed necessary immediately for a foreseeable number of years.

During a very exhaustive investigation and study, seven different schemes for increasing the capacity of the Aqueduct were carefully analyzed. Finally a construction program calling for stage development was planned and recommended whereby plant investment would not be far in excess of immediate needs, plant facilities would be adequate, and the danger of over-building would be minimized. This recommended program of construction called for the necessary work to be largely divided into two programs - the program for immediate construction, and the program for construction in 1960. Subsequent to the submission of the preliminary copies of the report, the Navy Department requested our recommendations for the most advantageous expenditure of the funds immediately available for improvements; said funds being only a fraction of the estimated funds required to accomplish the construction necessary to meet loads anticipated in 1960.

After carefully reviewing the situation and comparing the needs with the monies available, it was our conclusion and recommendation that the monies could be most advantageously expended for the construction of a new Booster Pumping Station at Tavernier, Florida, for increasing the pumping capacity at Florida City and at Marathon, Florida, and for increasing the raw water supply and treatment plant capacity. Accordingly, we were authorized to prepare plans and specifications for such additional facilities. The work of providing additional pumping capacity at Marathon and at Florida City, the new Booster Pumping Station at Tavernier, and one (1) new well at Florida City is presently under contract. It is expected that the work of providing the additional capacity in the water treatment plant will be under contract shortly. We shall attempt to review for you some of the factors and circumstances influencing the design of these recent additions.

First and foremost, in the development of any utility planning program, is a determination by estimate of the population to be served and the loads expected to result therefrom. It is a very simple matter to determine past population growth, but the projection of any population growth curve into the future requires careful consideration of numerous influencing and contributing factors. Census records indicate Key West as having a population of 12,927 in 1940, 14,246 in 1945, and 21,724 in 1950. The population in the Upper Keys in corresponding years was 1,151, 4,772 and 8,233 respectively. The official census figures for 1950 reported a population of 26,433 in Key West and 3,524 in the Upper Keys for 1950. These official figures could not be verified by any of the normal supporting data such as per capita water consumption, new water consumer connections, new electric consumer connections, post office receipts, etc. and were therefore rejected. It was also most evident to even the most casual observer that a pronounced growth in construction and resultant population had occurred in the Upper Keys between 1945 and 1950, although the official Federal census figures in 1950 would indicate a reduction in population over that time interval. Another interesting fact that became apparent in regard to population characteristics was that the civilian population within the Upper Keys area served by the Aqueduct increased approximately 100% during the Winter tourist season. This fact was established from the number of vehicles using the toll highway, from the records of postal earnings, and from the records of water consumption. The

future population growth of the Upper Keys and Key West will, in our opinion, be influenced by a number of factors. The area has only one (1) land route of ingress and egress. The land area for development is definitely limited, and the foreseeable economy of the area (except for Navy expenditures) will be limited primarily to commercial and pleasure fishing and tourists. With these factors in mind, our projected population curves indicate a population in the Upper Keys of approximately 11,500 in 1955, and a population of 29,500 simultaneously in Key West. In 1970, we estimate that the population in the Upper Keys will be approximately 23,500, and that the population in Key West will be approximately 49,500. However, one severe and destructive hurricane would, in all probability, have a depressing influence on any population forecasts.

The per capita water consumption by the residents of the Upper Keys and in Key West has always been very low when compared to State and National averages due primarily to the fact that fresh water has never been available in boundless quantities and has always been relatively high in cost. The per capita water consumption in 1945 was 13 gallons in the Upper Keys, and 61.6 gallons for the civilian population in Key West. In 1950, the per capita consumption was determined as being 28.3 gallons in the Upper Keys and 55.9 in Key West. This reversal in trend of the per capita consumption for the Upper Keys versus Key West is explained by the fact that the consumers in the Upper Keys secure their water directly from the Aqueduct, and the consumers in Key West must depend upon the remainder which is available. As has been previously pointed out, this "remainder" has been a constantly diminishing quantity during the past several years. It is our opinion that the per capita consumption of water in Key West will not exceed 75 gallons per capita per day in the foreseeable future and that the per capita consumption in the Upper Keys will similarly not exceed 50 gallons per capita per day. Accordingly, we estimate that the Navy plus civilian requirements will result in a water demand averaging 4.8 M. G. D. in 1955; 5.8 M. G. D. in 1960 and 7.9 M. G. D. in 1970.

In order to determine the maximum future usefulness of the existing 18-inch O. D. Steel pipe line, it was necessary to determine the extent, if any, of the interior deterioration of the pipe. With civilian consumer service connections located at random points along the entire length of the line, it is a practical impossibility to temporarily discontinue all consumer service connections for a period of time sufficient to make hydraulic observations of the pipe line while functioning under a fixed flow. The next best approach was to establish a hydraulic gradient from pressure observations made at numerous stations along the pipe line simultaneously. The hydraulic gradient resulting from such observations indicated that the pipe line had lost none of its original interior smoothness and that the "C" value was approximately 150. This evidence was further supported by the fact that results of chemical analyses indicated absolutely no increase in iron content of the water pumped through the pipe line. Further evidence of an excellent interior condition was to be found by observing the sections of pipe removed from the Aqueduct when connections and repairs were made during recent years.

After a determination of the loads to be supplied and the interior condition of the existing pipe line, the problem of design was considerable simplified. However, in designing additional facilities for the Key West Aqueduct, there are elements to be taken into consideration other than those normally encountered in the design of municipal water supply facilities. The area traversed by the pipe line has been previously described as a chain of islands and these



islands are so located that they are subject to the possibility of tropical hurricanes of varying intensity each season. Accordingly, a location offering as much protection from wind and water as is possible must be selected for a Booster Pumping Station. Electric power service which is presently available between Florida City and Marathon is overhead and is subject to power outages for extended periods of time. For that reason, electric power service at a point remotely located from the source of supply cannot be considered as dependable.

With these influencing factors in mind, a site for the new Booster Pumping Station at Tavernier, Florida was secured adjacent to the existing Diesel electric generating plant of the Florida Keys Electric Cooperative Association. Such a location permitted the use of electric driven centrifugal pumps (which are much cheaper in the first costs than Diesel driven pumps) because dependable power could be secured directly from the busses of the generating plant. Electric pumps also require less attention than Diesel driven pumps, and this circumstance will permit the part time use by the Navy of operating personnel from the electric generating plant in lieu of having to provide full time operating employees.

The new pumping station at Tavernier, will be initially equipped with two (2) electric driven centrifugal pumps, to be operated in parallel, each having a capacity of 2,000 G. P. M. at 560-feet T. D. H. The pumping station building, of reinforced concrete and reinforced masonry, has been so designed that it may be extended and additional pumps added very conveniently as future demands warrant. This pumping station will operate without storage facilities, and for that reason the amount of water being pumped must at all times be limited to the amount of water being delivered through the Aqueduct to the pumps. If operated uncontrolled, these pumps would undoubtedly strike a hydraulic balance so that a negative head would exist on the suction side of the pumps. However, such an operating condition would not be permissible because of existing consumer service connections to the Aqueduct, and a positive pressure must be maintained on the suction side of the pumps of not less than 20 to 25 pounds at all times. In order to accomplish this, the pumping station is to be provided with a motor operated and manually controlled throttling valve on the pump discharge header. Should the water pressure on the suction side of the pumps drop to 20 p.s.i. an electric alarm operated by a pressure switch will warn the operating personnel who can then make the necessary manual adjustments. Automatic facilities for maintaining a minimum positive pressure on the suction side of the pumps were not deemed practical of application in this instance.

One new Diesel driven centrifugal pump is being provided in the pumping stations at both Florida City and Marathon. These new pumps are being so installed and connected to the existing pump suction and discharge headers that the pumps may be run either in parallel or in series and so that an additional pump may be installed in the future with a minimum of inconvenience.

The pipe line distance between Florida City and the new pumping station at Tavernier is approximately 37 miles. With 520 of head available for friction loss, and using a "C" value of 150, that section of the pipe line has a capacity of 4.6 M. G. D. or 3200 G. P. M. The new Diesel pumping unit at Florida City will have a capacity of 2100 G. P. M., thereby giving this pumping station a firm pumping capacity of approximately 5.2 M. G. D. Therefore, it is expected that the Florida City Pumping Station will be able to deliver approximately 4.9 M. G. D. into the Aqueduct. The pipe line distance between the new Tavernier Pumping Station and the existing Pumping Station at

Marathon is approximately  $43\frac{1}{2}$  miles. Under similar friction loss conditions, it is estimated that the capacity of that section at the Aqueduct will be approximately 4.4 M. G. D. which is considerably less than the 5.75 M. G. D. theoretical capacity of the two (2) electric driven centrifugal pumps operating in parallel at Tavernier. However, the actual amount of water pumped South from Tavernier will be some intermediate quantity and will be possible of manual control by the throttling facilities previously described. The pipe line distance from the Marathon Pumping Station to the terminal facilities in Key West is approximately 49 miles, and by similar friction loss conditions, that section of the Aqueduct is estimated to have a carrying capacity of 3.8 M. G. D. The diesel driven pumps at Marathon would tend to pump water at a higher rate, but the Diesel engines can also be throttled if necessary to maintain desired conditions of pressure and flow.

The water treatment plant additions at Florida City will consist in the main of increasing the design capacity of the plant from 2.4 M. G. D. to 4.0 M. G. D. by the provision of additional spiractors and rapid sand filters.

However, it will be possible to operate the existing plant facilities plus the new units so that a plant output of 5 M. G. D. will result. Thus, it may be summarized that the additions to the Key West Aqueduct being provided at this time will result in facilities offering the following approximate maximum capacities:

- Water Treatment Plant 5.0 M. G. D.
- Florida City Pumping Station 4.9 M. G. D.
- Tavernier Pumping Station 4.6 M. G. D.
- Marathon Pumping Station 4.3 M. G. D.

The water resulting from the difference in pumping station capacity represents civilian consumption along that section of the Aqueduct plus line losses all normally expected. It is anticipated that the additional facilities being provided at this time will be adequate to meet anticipated requirements for both Navy and civilian personnel through 1955.